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Electromagnetic Band Gap Antenna with E-Shaped Defected Ground Structure for Communication Systems

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Abstract—A compact wideband miniaturized electromagnetic band gap (EBG) antenna has been proposed for communication systems with E-shaped defected ground structure (DGS). The proposed EBG antenna operates in the frequency range from 7.3 GHz to 9.4 GHz which includes the X band uplink frequency band (for sending modulated signals) from 7.9 to 8.4 GHz and the ITU-assigned downlink frequency band (for receiving signals) from 7.25 to 7.75 GHz. With EBG layer on the top layer, an E-shaped DGS structure has been introduced in the ground plane which results in the enhancement of measured impedance bandwidth from 300 MHz to 2100 MHz with good radiation characteristics.

1. INTRODUCTION

Most of the objectives for the integration of electromagnetic band gap (EBG) structures with antennas in the earlier research were either to steer the beam, suppress surface waves, or reflect in-phase incident waves in order to improve the performance of the antennas involved such as enhanced bandwidth, improved gain, and other properties [1–3]. The EBGs' composition prohibits the propagation of waves of a certain targeted band of frequencies, not including the harmonics in this case, from propagating through them and allows only a certain selected band of frequencies to pass through [4, 5]. Defected ground structures (DGSs) have also obtained great attention from researchers and scientists throughout the world due to their tremendous applications in almost all frequency bands, i.e., microwave frequency to millimeter wave frequencies. These types of structures are mainly used to enhance the overall properties of the antenna such as impedance bandwidth. These defected ground structures may be periodic or non-periodic as electromagnetic band gap and photonic band gap structures. Basically, in terms of enhancing the resulting impedance bandwidth of the antenna structure, these defected ground structures are being used. However due to a defect in the ground plane, there can be reduction in the gain of the antenna or can result in the degradation of the radiation characteristics. DGS disturbs the shield current distribution in the ground plane because of the defect in the ground. This disturbance will change characteristics of a transmission line such as line capacitance and inductance. In short, any defect etched in the ground plane of the microstrip can give rise to increasing effective capacitance and inductance. But with proper optimization of the antenna structure, researchers can obtain wide impedance bandwidth along with good radiation properties. For this, researchers have to optimize their antenna structures so well that they can cope with these constraints' relation to radiation [6, 7].

In the past years, various novel defected ground structures have been proposed, and they now become one of the most interesting areas of research owing to their extensive applicability in microwave circuits [8–10]. Many passive and active microwave and millimeter devices have been developed to

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suppress the harmonics and realize the compact physical dimensions of circuits for the design flow of circuits with DGS comparatively simple [11–13].

In some cases, the patch has been shorted to the ground plane for the miniaturization of patch antenna. By using this type of technique, the size is reduced to a greater extent, but the resulting gain also decreases [14–17]. Artificial magnetic substrate can also be used for the purpose of miniaturization, but this method results in narrow impedance bandwidth response. Most of the antennas have shown wideband impedance bandwidth, but the resulting radiation properties have been degraded. Some researchers have proposed U-shaped slots; some have proposed V-shaped slots; some have used stacked structure or multilayered the overall structure [18–36]. In this paper, we have put an effort using both EBG and DGS structures to increase the impedance bandwidth of the antenna along with the improvement in the radiation properties that finally resulted in a good performance antenna design for the said frequency of operation. The antenna has provided better properties than conventional antenna also for the same frequency range of operation.

In the present paper, a compact miniaturized EBG antenna is proposed with wide impedance bandwidth and improved radiation properties. The improvement in the resulting radiation characteristics has been achieved by incorporating an EBG layer around the main fed patch along with a fully optimized E-shaped defect in the ground plane. The proposed antenna can be a good solution for the uplink and downlink frequency band around 7 GHz and 9 GHz.

2. ANTENNA DESIGN AND METHOD OF MEASUREMENT

In order to obtain the final antenna prototype design, a number of steps of optimizations have been performed using a commercially available simulation software, i.e., CST (computer simulation technology) studio suite, a full wave 3D electromagnetic wave simulation software. Using the simulation software, main antenna parameters such as S-parameters (S_{11}) and impedance (Z) can be observed. In addition to these parameters, radiation characteristics of the proposed antenna design can be obtained such as radiation patterns, antenna gain, and current/field distributions. After obtaining satisfactory/desired results for all these parameters, one can proceed for experimental validations. For experimental measurements, Vector Network Analyzer (VNA) can be used as a standard testing instrument for antenna designs. VNA will be connected to the antenna prototype using a 50-ohm cable and connector, and the results can be obtained on the network analyzer. These results should match with the simulation results in order to validate the design performance. After this, the antenna can further be tested in an anechoic chamber for measuring the radiation characteristics such as pattern, antenna gain, etc.

The antenna geometry for a conventional optimized circular ring microstrip patch antenna is shown

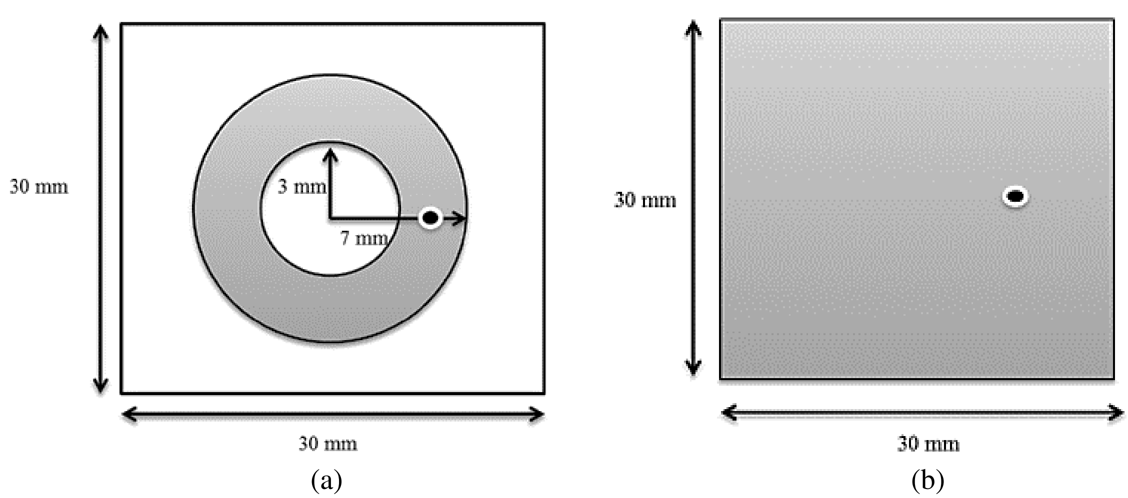


Figure 1. Geometry of conventional antenna. (a) Top view. (b) Bottom view.

in Figure 1. For this structure, the ring has been optimized to operate in the required frequency of operation. The inner radius of the circular ring is 3 mm, and the outer radius of the circular ring is 7 mm. The dimensions of the substrate and ground plane are (30 mm × 30 mm). The antenna has been proposed on a low cost commercially available substrate, i.e., FR4. The thickness of the substrate is 1.60 mm with a loss tangent of 0.009 and dielectric constant 4.3.

3. PARAMETERS AND RESULTS

The S-parameters for this conventional patch antenna with full unperturbed ground plane are shown in Figure 2. The antenna has been fully optimized with various possibilities. Figure 2(a) shows the feed point variation, i.e., 'x' (for minimum $(3 + x)$), and Figure 2(b) shows the variation in the overall size of antenna. Finally, the antenna with required dimension and parameters is chosen (at $x = 2$ and

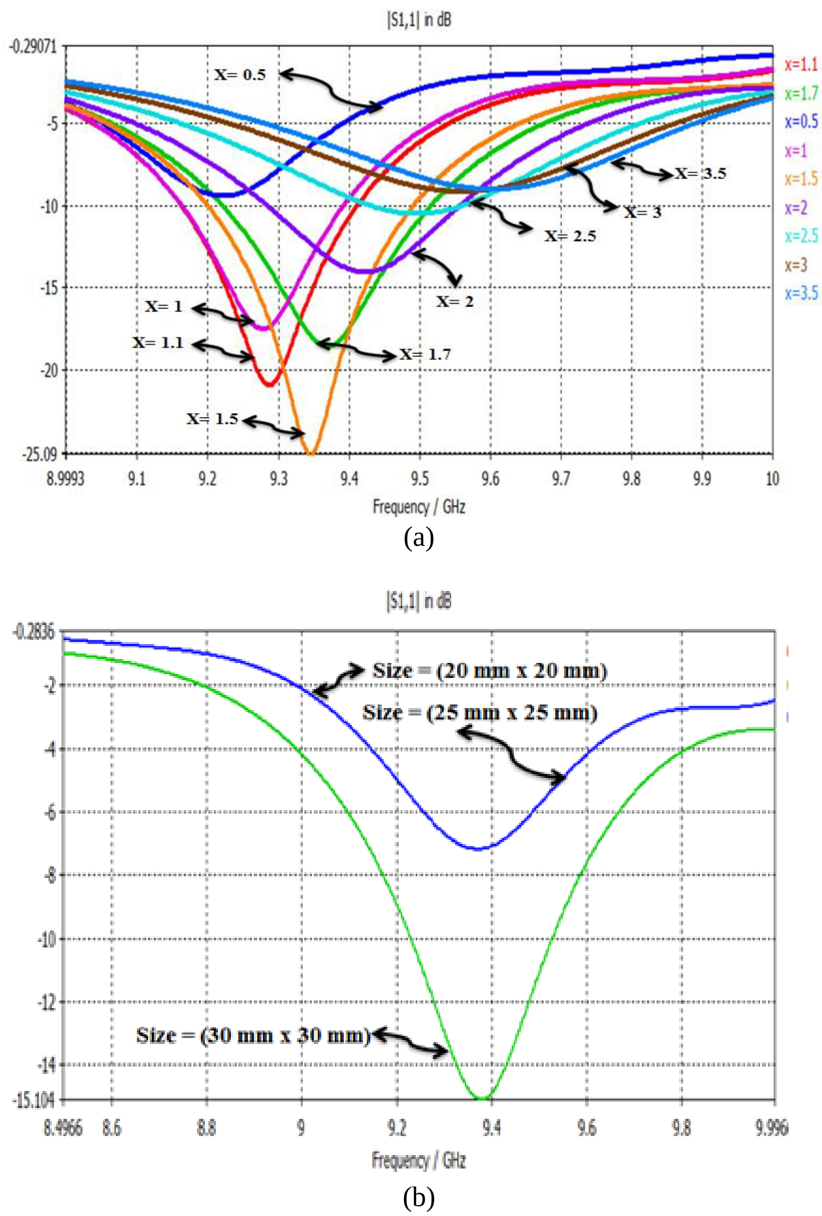


Figure 2. S-parameter variation with frequency for conventional antenna. (a) Feed variation in terms of 'x' from the origin. (b) Overall antenna size variation.

size = (30 mm × 30 mm)). The resonant frequency of 9.4 GHz has been chosen after comparing results of all parameters like bandwidth, overall size of antenna, and gain at different resonant frequencies. Although the antenna return loss is 14 dB at a reference of 10 dB, the impedance bandwidth calculated from the graph is very narrow. An impedance bandwidth of just 300 MHz has been obtained which is very less for applications at the required frequency band. The maximum antenna gain obtained at the resonant frequency of 9.4 GHz is about 3.4 dB. So, in order to increase the resulting impedance bandwidth, we need to apply DGS with proper optimization.

Figure 3(a) shows the circular ring patch antenna with first iteration in the ground plane. Half of the ground plane has been removed in order to check its resulting properties. Keeping same dimensions for the circular ring and substrate, the ground has been removed by 15 mm. Now the ground has dimensions of (15 mm × 30 mm).

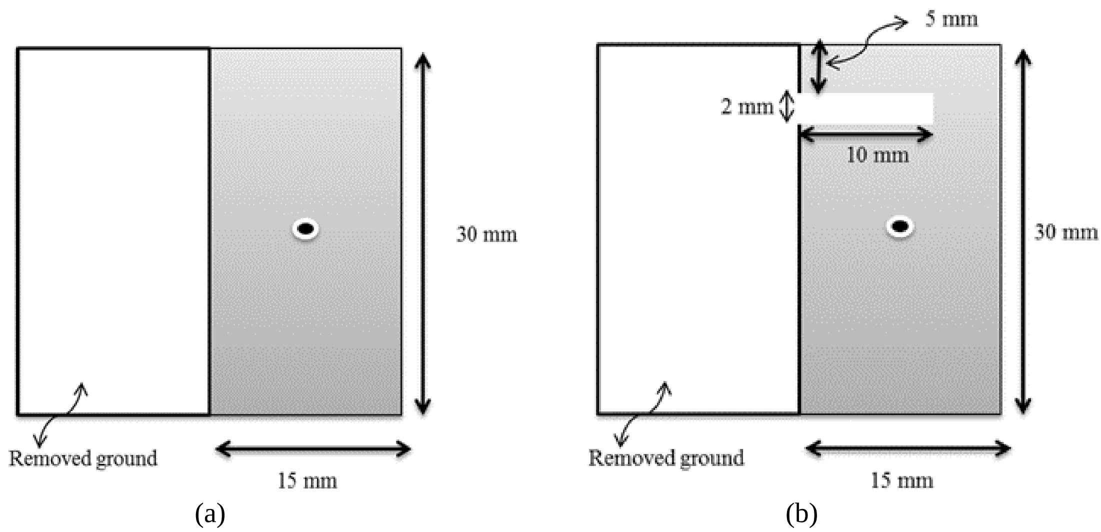


Figure 3. Ground defects (a) first iteration, (b) second iteration.

Figure 8(a) shows the variation of S-parameters obtained with frequency for this defected ground structure. It can be seen from the graph that the resonant frequency has been shifted now to the lower side. This structure is now operating at a frequency of around 9.1 GHz.

At this resonant frequency, the impedance bandwidth obtained is 800 MHz resulting in an increase of 500 MHz from the conventional antenna. The bandwidth has been improved from 300 MHz to 800 MHz with size reduction in the first iteration. It has been observed that although the bandwidth is enhanced, the gain is reduced to 2 dB.

Further, the antenna structure has been introduced with slots in the half-removed ground plane. A slot of width 2 mm and length 10 mm has been introduced as shown in Figure 3(b). This dimension of the slot has been optimized to get improved performance of the antenna structure.

Figure 8(a) shows the variation of S-parameters with frequency for the second iteration. It can be clearly seen from the graph that the impedance bandwidth has been further enhanced to 900 MHz with a further shift in the resonant frequency to 9 GHz which leads to reduction in size and a return loss of 13 dB. It has been observed that the gain is reduced again to 1.6 dB.

With the previous iterations, we have been able to enhance the impedance bandwidth to a good extent, but we still need to improve our radiation properties, i.e., gain. So, an EBG layer has been introduced around the fed patch on the top layer along with a slot as the second iteration in the ground plane at a particular distance. The final dimensions of the slot, i.e., the length, width, and distance have been fully optimized to obtain the best antenna characteristics. The geometry of the final antenna with the third iteration and EBG is shown in Figure 4. EBG layer elements consist of circular shaped elements with each of radii 1 mm around the fed patch.

The proposed antenna has a slotted ground plane with dimensions (15 mm × 30 mm). The ground

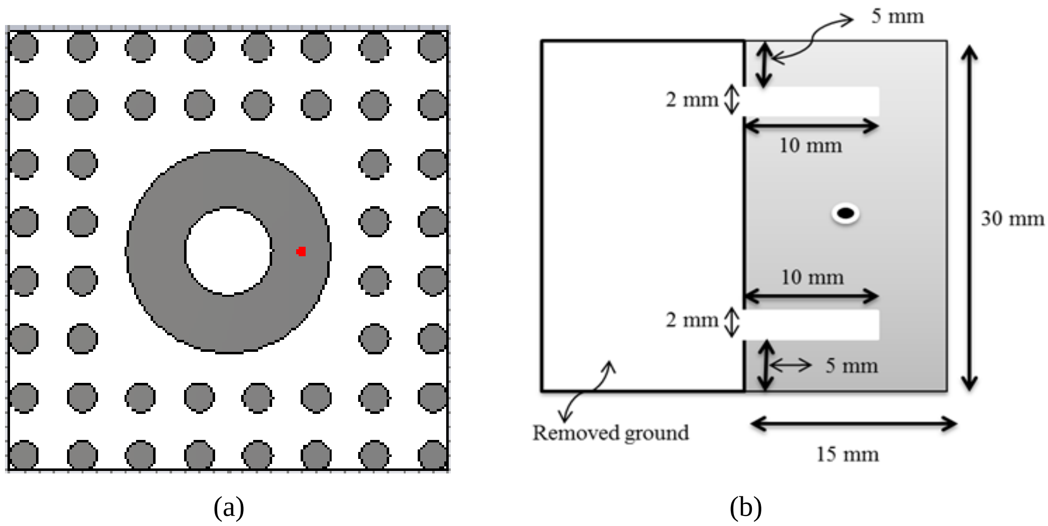


Figure 4. Final proposed EBG antenna with E-shaped DGS: (a) Top view with EBG layer, (b) bottom view with E-shaped DGS (third iteration).

now has an E-shaped structure which finally gives the best properties with regard to its impedance bandwidth, antenna gain, and impedance matching. The substrate has dimensions (30 mm × 30 mm) with thickness 1.6 mm. The complete geometry of top and bottom of the proposed antenna can be seen in Figure 4.

Figure 5 shows the position variation study of the slots in the ground plane of the proposed antenna. The slot positions have been varied at different distances from the center of the ground plane in order to obtain final parameters where for vertical slot position from center, $Y_{\min} = (6 + g)$ and $Y_{\max} = (8 + g)$. At $g = 2$ mm, it can be seen that the impedance bandwidth obtained is maximum.

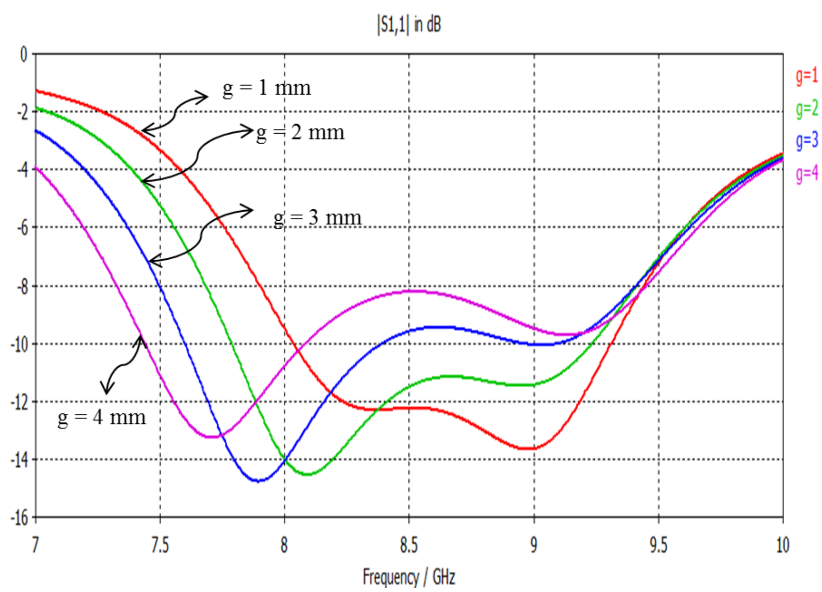


Figure 5. Slot position variation in the ground plane.

Figure 6 shows the values of maximum directivity obtained at the resonant frequency range at different positions. It has been observed that at $g = 2$ the maximum directivity has been achieved by also taking into account the maximum impedance bandwidth at the same position.

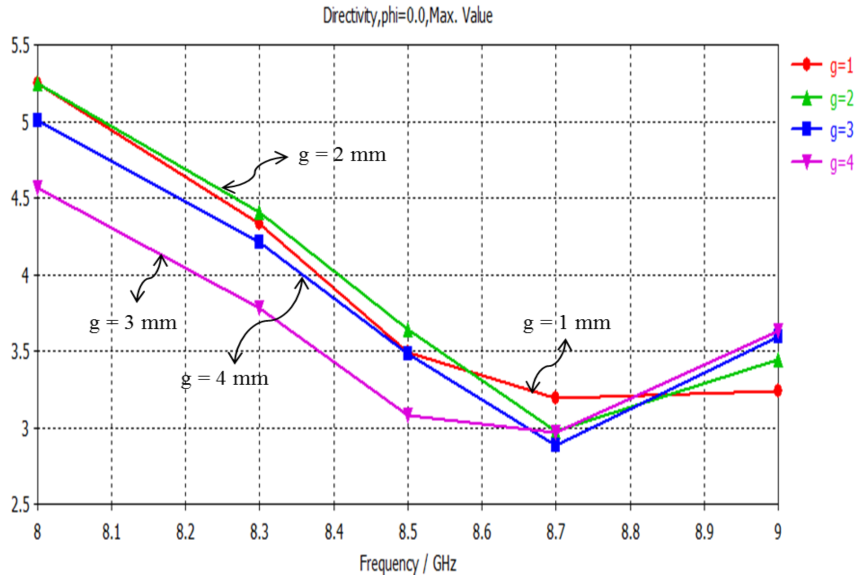


Figure 6. Maximum directivity for different slot positions.

4. PROTOTYPE DESIGN

The prototype of the designed antenna is shown in Figure 7 with a coaxial feed at a distance of 5 mm from the center of the circular ring. This feed point has been optimized with the help of simulation software CST studio suite to obtain good impedance matching (around 50 ohms) at the resonant frequency along

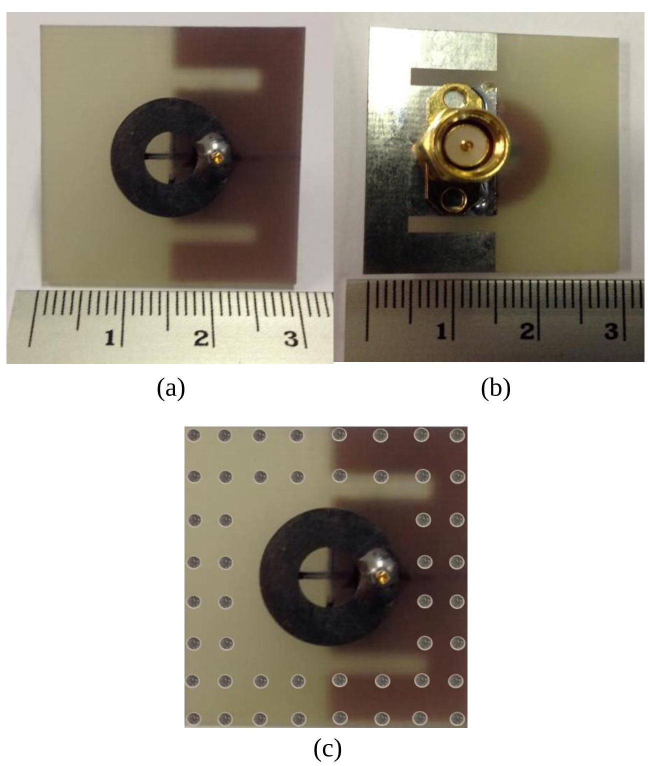
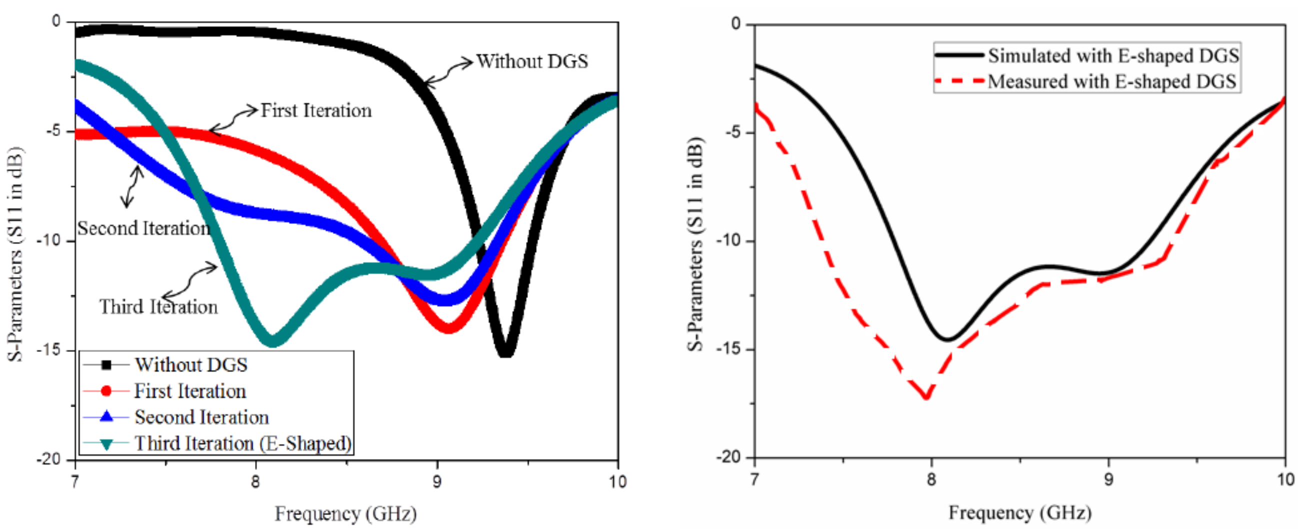


Figure 7. Prototype of the proposed EBG based E-shaped DGS antenna. (a) Top view without EBG. (b) Bottom view. (c) Top view with EBG.

with good enhanced antenna characteristics. For the measurement of prototype design, an Agilent Vector Network Analyzer has been used working up to 50 GHz.

Figure 8(a) shows the comparative study of the increase in bandwidth for different iterations. Figure 8(b) shows the S-parameter variation with frequency for the proposed EBG antenna with an E-shaped DGS. It can be seen from this graph that the antenna operates over a wide range of frequency. The measured bandwidth obtained is about 2100 MHz from 7.3 GHz to 9.4 GHz. A good return loss of 15 dB has also been obtained with good impedance matching (around 50 ohms) at the frequency of 8 GHz. The antenna has been tested, and it has been found that the simulated and experimentally measured results are in very good agreement as can be seen in Figure 8(b). Figure 9 shows the simulated and measured input impedance graphs for 50 ohms impedance matching.

Figure 10 shows the antenna gain obtained at the resonant frequency of 8 GHz in the main lobe direction of 180.0 deg within 3 dB angular width in the direction 220.3 deg. It has been observed from



(a) (b)

Figure 8. S-parameter variation with frequency. (a) Bandwidth variation for different iteration (defect) in the ground. (b) Results for proposed EBG antenna with E-shaped DGS.

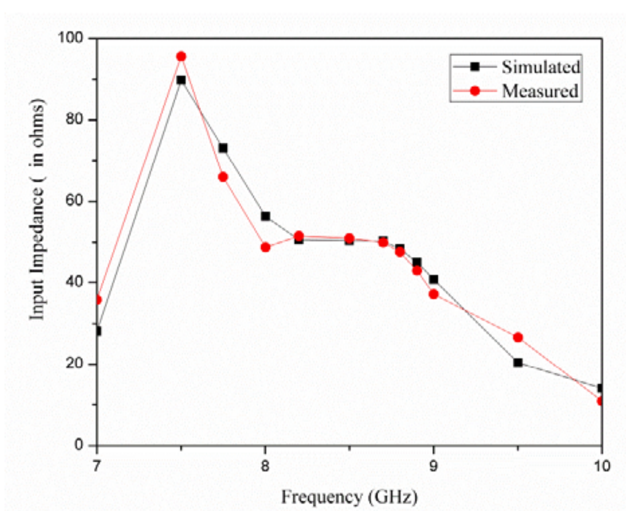


Figure 9. Input Impedance variation with frequency.

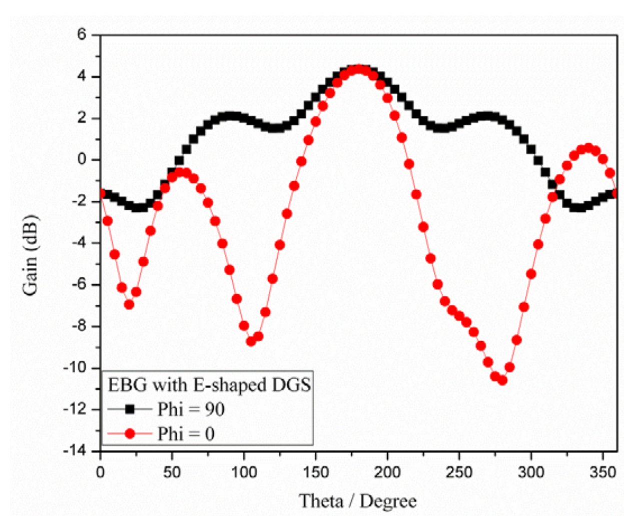
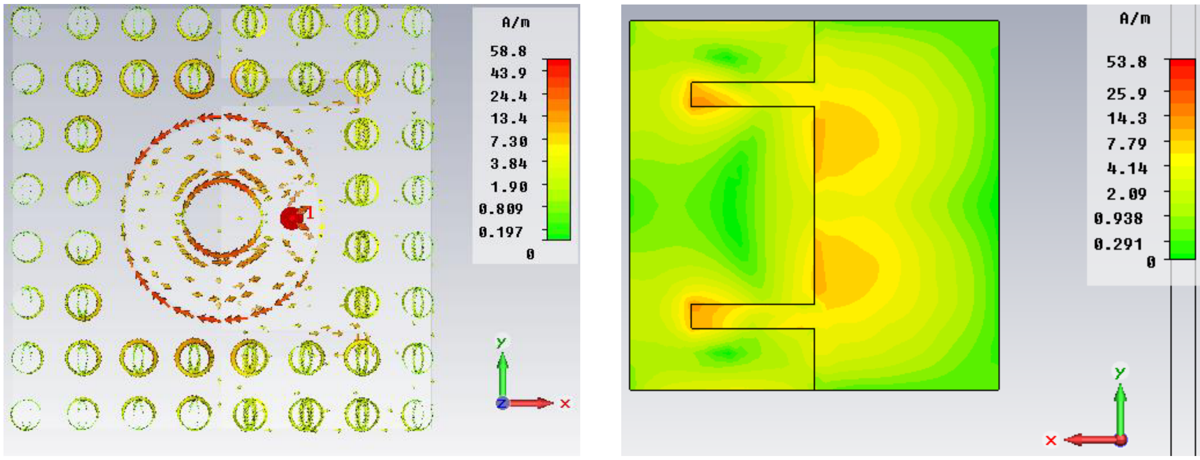


Figure 10. Antenna gain for final prototype.

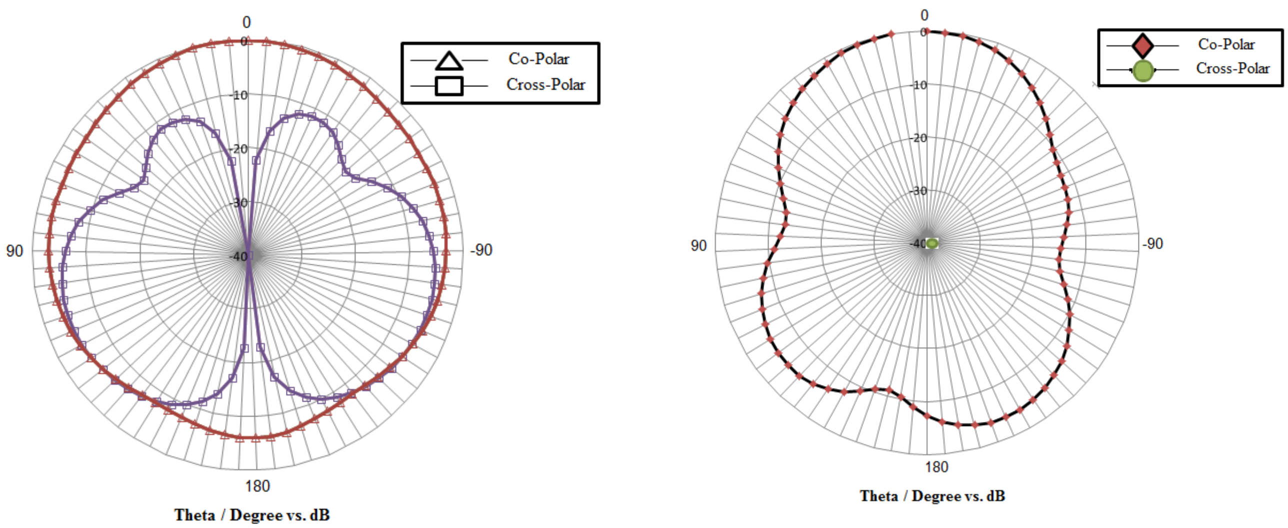


(a) (b)

Figure 11. Current distribution for the proposed antenna. (a) Top view of proposed antenna. (b) Bottom view of the proposed antenna.

the Cartesian plot of the antenna gain that the antenna has improved its gain to 4.5 dB. The current distribution graph is shown in Figure 11. It can be easily observed from these graphs how well the proposed antenna behaves with this type of structure and dimensions.

Figure 12 shows the normalized radiation patterns for YZ-plane and XZ-plane. Figure 12(a) shows the co-polar and cross-polar graph plots in YZ-plane. Figure 12(b) shows the co-polar and cross-polar graph plots in XZ-plane. Here for cross-polar component, the cross-polarization is even less than -40 dB (< -40 dB), so can be neglected and represented by a dot in the graph.



(a) (b)

Figure 12. Normalized radiation patterns for the proposed antenna. (a) YZ-plane. (b) XZ-plane.

Finally, it can be analyzed that the final proposed EBG antenna with an E-shaped DGS shows overall good antenna characteristics with a reduced size, wide impedance bandwidth, and good antenna gain.

5. CONCLUSIONS

A compact miniaturized wideband EBG antenna design has been proposed with an E-shaped defected ground structure (DGS). The proposed antenna has been obtained with a wide measured impedance bandwidth of 2100 MHz with an antenna gain of 4.5 dB. The introduction of the EBG antenna with a DGS structure has finally resulted in the improvement of the antenna properties. The frequency of operation of this proposed antenna makes it a good candidate for the X band uplink frequency band (for sending modulated signals) and the ITU-assigned downlink frequency band (for receiving signals).

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Louis WY Liu has contributed equally as co-first author.

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